Rare Kaon Decays Review and Prospects

Augusto Ceccucci/CERN

- Physics
- State of the Art
- Prospects

XL\textsuperscript{th} Rencontres de Moriond,
EW Interactions and Unified Theories
Motivations

• Search for explicit violation of Standard Model
  – Lepton Flavour Violation (LFV)

• CP-Violation and Quark Mixing
  – Flavour Changing Neutral Currents (FCNC)
  – Unique probe of $s \to d$ transitions
  – Small theoretical errors [for some decays!]

• Other tests of fundamental symmetries
  – CP,CPT (e.g. $K_S \to 3\pi^0$ in G. Lanfranchi’s talk, $K_L \to \pi^+\pi^-e^+e^-$)
Lepton Flavour Violation
Puzzling replication of generations

• Foreseen in many extensions of SM:
  – Generation-Changing gauge interactions (Cahn, Harari (1980))
  – Left-Right symmetry
  – Technicolor
  – Compositeness
  – Super-symmetry

\[ \Delta G = 0 \]

\[ \Delta G = 1 \]

\[ \mu \rightarrow e \, \gamma \]

\[ K^+ \rightarrow \pi^+ \mu^+ e^- \]

\[ K^0 \rightarrow e^+ e^- \]

\[ K_L \rightarrow \mu e \]
$K^+ \rightarrow \pi^+ \mu^+ e^-$ AGS – E865

New Result based on 1998 data: hep-ph/0502020
BR($K^+ \rightarrow \pi^+ \mu^+ e^-$) < 2.2 $\times 10^{-11}$ (90%CL)
Combined with previous results:
BR($K^+ \rightarrow \pi^+ \mu^+ e^-$) < 1.2 $\times 10^{-11}$ (90%CL)

~10$^8$ $K^+$ /s
~3 $10^9$ part /pulse
$P_K$ ~6 GeV/c

Backgrounds (examples):
$K^+ \rightarrow \pi^+ \pi^+ \pi^- \rightarrow \pi^+ \mu^+ \nu e^- \nu$
$K^+ \rightarrow \pi^+ \pi^0 \rightarrow \mu^+ \nu e^+ e^- \gamma$
$K^+ \rightarrow \mu^+ \pi^0 \nu \rightarrow \mu^+ e^+ e^- \gamma$
Accidentals

8 Candidates consistent with expected background of 8.2 ±1.9 $N_{sig} < 2.4$
Lower bounds for generation-changing bosons (g_X/g_W~1)

\[
\frac{Br(K^+ \rightarrow \pi^+ \mu^+ e^-)}{Br(K^+ \rightarrow \pi^0 \mu^+ \nu)} = 16 \frac{1}{\sin^2 \vartheta_C} \left( \frac{g_X}{g_W} \right)^4 \left( \frac{M_W}{M_X} \right)^4
\]

\[
\begin{array}{c}
\text{E871} \\
\begin{array}{c}
\bar{s} \\
\mu^+ \\
e^-
\end{array}
\end{array}
\begin{array}{c}
\text{E865} \\
\begin{array}{c}
\bar{s} \\
\mu^+ \\
e^-
\end{array}
\end{array}
\begin{array}{c}
\text{KTeV} \\
\begin{array}{c}
\bar{s} \\
\mu^+ \\
e^-
\end{array}
\end{array}
\]

\[
\begin{aligned}
\mathcal{B}(K_L^0 \rightarrow \mu^\pm e^\mp) &< 4.7 \times 10^{-12} & >150 \text{ TeV/c}^2 \\
\mathcal{B}(K^+ \rightarrow \pi^+ \mu^+ e^-) &< 1.2 \times 10^{-11} & >80 \text{ TeV/c}^2 \\
\mathcal{B}(K_L^0 \rightarrow \pi^0 \mu^+ e^-) &< 3.2 \times 10^{-10} & >37 \text{ TeV/c}^2
\end{aligned}
\]

Further progress on LFV (charged leptons) expected in muons
• \( \mu \rightarrow e \gamma \) PSI
• \( \mu^- N \rightarrow e^- N \) MECO@AGS, J-PARC
CP-Violation and Quark Mixing
CKM matrix and CP-Violation

Quark mixing is described by the Cabibbo-Kobayashi-Maskawa (CKM) matrix

\[
\begin{pmatrix}
    d' \\
    s' \\
    b'
\end{pmatrix}
= 
\begin{pmatrix}
    V_{ud} & V_{us} & V_{ub} \\
    V_{cd} & V_{cs} & V_{cb} \\
    V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
    d \\
    s \\
    b
\end{pmatrix}
\]

KM mechanism:

\[N_g = 2 \quad N_{\text{phase}} = 0 \Rightarrow \text{No CP-Violation}\]

\[N_g = 3 \quad N_{\text{phase}} = 1 \Rightarrow \text{CP-Violation Possible}\]

\[\text{e.g. } \text{Im} \lambda_t = \text{Im} V_{ts}^* V_{td} \neq 0 \Rightarrow \varphi^\prime\]

KM mechanism appears to be the main source of CP-violation in quarks:

- Direct-CP Violation exists: \(\varepsilon' / \varepsilon \neq 0\) NA48, KTeV
- CP violation in the B meson sector: \(A_{\text{CP}}(J/\psi K_s)\), BaBar, Belle

Now look for inconsistencies in SM using independent observables affected by small theoretical uncertainties and different sensitivity to new physics
Kaon Rare Decays and the SM

Kaons provide quantitative tests of SM independent from B mesons...

...and a large window of opportunity exists!

$$|V_{td}|$$

$$\begin{align*}
K_L \rightarrow \pi^0 \nu \bar{\nu} \\
K_L \rightarrow \pi^0 e^+ e^- \\
K_L \rightarrow \pi^0 e^- e^- \\
K_L \rightarrow \pi^0 \gamma \gamma \\
K_L \rightarrow e e \gamma \gamma
\end{align*}$$

$$\lambda_t = A^2 \lambda^5 \eta$$

$$\text{Im} \lambda_t = A^2 \lambda^5 \eta$$

$$\text{Re} \lambda_t = A^2 \lambda^5 \rho$$

G. Isidori
$K \rightarrow \pi \nu \nu$: Theory in Standard Model

\[ B(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = \kappa_+ \cdot \left[ \left( \frac{\text{Im} \lambda_t}{\lambda^5} X(x_t) \right)^2 + \left( \frac{\text{Re} \lambda_t}{\lambda^5} X(x_t) + \frac{\text{Re} \lambda_c}{\lambda} P_c(X) \right)^2 \right] \]

\[ B(K_L^0 \rightarrow \pi^0 \nu \bar{\nu}) = \kappa_L \cdot \left( \frac{\text{Im} \lambda_t}{\lambda^5} X(x_t) \right)^2 \]

\[ \lambda = V_{us}^* \]
\[ \lambda_c = V_{cs}^* V_{cd} \]
\[ \lambda_t = V_{ts}^* V_{td} \]

\[ \kappa_+ = r_{K^+} \cdot \frac{3\alpha^2 Br(K^+ \rightarrow \pi^0 e^+ \nu)}{2\pi^2 \sin^4 \theta_W} \cdot \lambda^8 \]

The Hadronic Matrix Element is measured and isospin rotated (~10% correction)
Predictions in SM

\[ BR(K^+ \to \pi^+ \nu \bar{\nu}) = (8.0 \pm 1.1) \times 10^{-11} \] (latest CKM workshop)

Error \sim 14\% Mainly parametric
Theory error due to charm (Buras04):

\[ P_c(X) = 0.389 \pm 0.033(m_c) \pm 0.045(\mu_c) \pm 0.010(\alpha_s) \]

Largest contribution from scale error. To be reduced by NNLO calculation

Refer to Christopher Smith’s talk on long distance contributions

\[ BR(K_L^0 \to \pi^0 \nu \bar{\nu}) = (3.0 \pm 0.6) \times 10^{-11} \] (Buras et al. 04)

The error is almost purely parametric
Possibly the Cleanest SM test

- In $K \rightarrow \pi \nu \bar{\nu}$ The phase $\beta$ derives from $Z^0$ diagrams ($\Delta S=1$) whereas in $A(J/\psi K_S)$ originates in the $B_d^0 - \bar{B}_d^0$ box diagram ($\Delta B=2$)
- Any non-minimal contribution to $Z^0$ diagrams would be signalled by a violation of the relation:
  \[
  (\sin 2\beta)_{K \rightarrow \pi \nu \bar{\nu}} = (\sin 2\beta)_{B \rightarrow J/\psi K_S}
  \]
- A deviation from the predicted rates of SM would be a clear indication of new physics
- Complementary programme to the high energy frontier:
  - When new physics will appear at the Tevatron/LHC, the rare decays may help to understand the nature of it
# Some BSM Predictions

Compiled by S. Kettel

\[
BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \times 10^{-11} \quad BR(K_L^0 \rightarrow \pi^0 \nu \bar{\nu}) \times 10^{-11}
\]

<table>
<thead>
<tr>
<th>Theory</th>
<th>SM</th>
<th>MFV</th>
<th>EEWP</th>
<th>EDSQ</th>
<th>MSSM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8.0 ± 1.1</td>
<td>19.1</td>
<td>7.5 ± 2.1</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>3.0 ± 0.6</td>
<td>9.9</td>
<td>31 ± 10</td>
<td>10</td>
<td>50</td>
</tr>
</tbody>
</table>

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**Diagrams:**

1. **Left Diagram:**
   - Vertices: $s$, $d$, $\nu$, $\tilde{u}$, $\nu$
   - Process: $s \chi \rightarrow d \tilde{u}$

2. **Right Diagram:**
   - Vertices: $s$, $\tilde{u}$, $l$, $\chi$
   - Process: $s \chi \rightarrow s \tilde{u} l \chi$

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Moriond EW, March 10, 2005  A. Ceccucci, CERN
\[ K^0_L \rightarrow \pi^0 \nu\nu : \text{State of the Art} \]

KTeV 1997 Data

Dalitz Analysis

Still far from the model independent limit:

\[ BR(K^0 \rightarrow \pi^0 \nu\nu) < 4.4 \times BR(K^+ \pi^- \nu\nu) \sim 1.4 \times 10^{-9} \]


\[ BR(K_L \rightarrow \pi^0 \nu\nu) < 5.9 \times 10^{-7} \] (\[\pi^0 \rightarrow ee\gamma\], 1997 Data) [PRD 61,072006 (2000)]

\[ BR(K_L \rightarrow \pi^0 \nu\nu) < 1.6 \times 10^{-6} \] (\[\pi^0 \rightarrow \gamma\gamma\], 1997 1 Day) [PLB 447, 240 (1999)]
$K^+ \to \pi^+ \nu\nu$: State of the art

$\text{BR}(K^+ \to \pi^+ \nu\nu) = 1.47^{+1.30}_{-0.89} \times 10^{-10}$

• Compatible with SM within errors
Setting the bar for the next generation of $K^+ \rightarrow \pi^+ \nu \nu$ experiments

Current constraint on $\rho, \eta$ plane

100 events  
Mean=SM

100 events  
Mean=E787/949
$K^0_L \rightarrow \pi^0 e^+e^-$ and $K^0_L \rightarrow \pi^0 \mu^+\mu^-$

I refer you to the talks by D. Greynat, C. Smith and L. Bellantoni

Similar physics interest as $K^0_L \rightarrow \pi^0 \nu \nu$. Complicated by long distance contributions and radiative backgrounds

Indirect CPV
(Measured by NA48/1 but experimental error is still large)

Direct CPV
KTeV: $K_L \rightarrow \pi^0 ee$

1999 data

PRL93, 021805 (2004)

- One candidate in the signal box

$BR(K_L \rightarrow \pi^0 ee) < 3.5 \times 10^{-10} @90\% CL$

- Combining 1997 and 1999:

$BR(K_L \rightarrow \pi^0 ee) < 2.8 \times 10^{-10} @90\% CL$

Expected Background $0.99 \pm 0.35$ events
KTeV: $K^0_L \rightarrow \pi^0\mu\mu$

2 events in signal region

$$\text{BR}(K^0_L \rightarrow \pi^0\mu\mu) < 3.8 \times 10^{-10} \, (90\% \, \text{C.L.})$$ [PRL 86, 5425 (2001)]
$K^0_S \rightarrow \pi^0 e^+e^-$ and $K^0_S \rightarrow \pi^0 \mu^+\mu^-$

$BR(K_S \rightarrow \pi^0 ee) \times 10^{-9} = 5.8^{+2.8}_{-2.3}\text{(stat)} \pm 0.8\text{(syst)}$  

$|a_s| = 1.06^{+0.26}_{-0.21}\text{(stat)} \pm 0.07\text{(syst)}$  

PLB 576 (2003)

$BR(K_S \rightarrow \pi^0 \mu\mu) \times 10^{-9} = 2.9^{+1.4}_{-1.2}\text{(stat)} \pm 0.2\text{(syst)}$  

$|a_s| = 1.55^{+0.38}_{-0.32}\text{(stat)} \pm 0.05\text{(syst)}$  

PLB 599 (2004)
$K_L^0 \rightarrow \pi^0 e^+ e^-$ in SM

Thank to the $K_S$ measurements, the $K_L$ BR can now be predicted

*Interference between short- and long-distance physics*

\[ Br(K_L \rightarrow \pi^0 \mu^+ \mu^-) \times 10^{-12} \]

Constructive

\[ B_{K_L^0 \rightarrow \pi^0 e^+ e^-} = 3.7^{+1.1}_{-0.9} \times 10^{-11} \]
\[ B_{K_L^0 \rightarrow \pi^0 \mu^+ \mu^-} = 1.5^{+0.3}_{-0.3} \times 10^{-11} \]

now favored by two independent analyses*

Destructive

\[ B_{K_L^0 \rightarrow \pi^0 e^+ e^-} = 1.7^{+0.7}_{-0.6} \times 10^{-11} \]
\[ B_{K_L^0 \rightarrow \pi^0 \mu^+ \mu^-} = 1.0^{+0.2}_{-0.2} \times 10^{-11} \]

*S. Friot, D. Greynat, E. de Rafael, hep-ph/0404136, PL B 595
$K^0_L \rightarrow \pi^0 ee (\mu\mu)$: Sensitivity to NP

Isidori, Unterdorfer, Smith:

Fleischer et al*:

Ratios of $B_d \rightarrow K\pi$ modes could be explained by enhanced electroweak penguins which, in turn, would enhance the $K_L$ BR’s:

$$B_{K^0_L \rightarrow \pi^0 e^+ e^-}^{NP} = 9.0^{+1.6}_{-1.6} \times 10^{-11}$$

$$B_{K^0_L \rightarrow \pi^0 \mu^+ \mu^-}^{NP} = 4.3^{+0.7}_{-0.7} \times 10^{-11}$$

Prospects

- $K^0_L \rightarrow \pi^0 \nu \nu$
  - Large window of opportunity exists.
  - Upper limit is 4 order of magnitude from the SM prediction
  - Expect results from data collected by E391a (proposed SES~$3 \times 10^{-10}$)
  - Next experiment KOPIO@ BNL

- $K^0_L \rightarrow \pi^0 ee (\mu \mu)$
  - Long distance contributions under better control
  - Measurement of $K_S$ modes has allowed SM prediction
  - $K_S$ rates to be better measured (KLOE?)
  - Background limited (study time dep. Interference?)
  - 100-fold increase in kaon flux to be envisaged

- $K^+ \rightarrow \pi^+ \nu \nu$
  - The situation is different: 3 clean events are published
  - Experiment in agreement with SM
  - Next round of exp. need to collect $O(100)$ events to be useful
  - Move from stopped to in flight experiments
$K_L \rightarrow \pi^0 \nu \nu$ E391a@PS-KEK

- First dedicated experiment to search for $K_L \rightarrow \pi^0 \nu \nu$
- Proposed SES~$3 \times 10^{-10}$
- Based on pencil kaon beam and photon vetoes
- Collecting data now: waiting for results
- This is a Stage I project for further study at J-PARC
$K_L \rightarrow \pi^0 \nu\nu$  KOPIO@BNL

- Proposed to collect 60 $K_L \rightarrow \pi^0 \nu\nu$ events with S/B ~2  ($\text{Im } \lambda_t$ to 15%)
- Measure as much as possible:
  - Energy, Position and Angle for each photon
- Work in the Kaon Center of Mass
  - Micro-bunched AGS beam
  - Use TOF to measure $K_L$ momentum
- Start construction in 2005?
KOPIO@BNL

Status:
Approved,
Currently under cost review
Data Taking: 2011-?
Prospects on $K^+ \rightarrow \pi^+ \nu\bar{\nu}$

• **Decays at rest:**
  - Window of opportunity to accumulate more data at BNL until 2010 (before KOPIO data taking starts)
  - Ideas to pursue stopped kaon decays in Japan
  - Established technique...
  - ...but hard to extrapolate to O(100) events

• **Decays in flight**
  - Large acceptances, good photon rejection
  - Separated beam: FNAL CKM (Approved but Not Ratified)
    • Limited to about $P_K < 30$ GeV/c
  - Un-separated beam: CERN-NA48/3, FNAL-P940
    • Limited by rate in beam trackers
NA48/3: SPSC-I229

- Collect $80 K^+\rightarrow\pi^+\nu\nu$ events in about two years of data taking for:
  - $4 \times 10^{12}$ Kaon decays/SPS year
  - $\text{BR}(K^+\rightarrow\pi^+\nu\nu) \sim 10^{-10}$
  - Acceptance $\sim 10\%$
  - Absolute advantage:
    High energy kaon beam: $>35$ GeV of EM energy deposited in the vetoes very difficult to miss $\pi^0$ !!
  - Disadvantage:
    $\sim 1$ GHz particle rate in beam tracker
800 MHz ($\pi/K/p$)

Only the upstream detectors see the 800 MHz beam

10 MHz Kaon decays

undetected

Moriond EW, March 10, 2005

A. Ceccucci, CERN
Acceptance

\[ 0 < m^2_{\text{miss}} < 0.01 \ (GeV / c^2)^2 \]

Region I

14 < \( p_{\pi} \) (GeV / c)

14 < \( p_{\pi} \) (GeV / c) < 40

14 < \( p_{\pi} \) (GeV / c) < 30

\[ P_K = 75 \text{ GeV} / c \quad P_{\pi} < 40 \text{ GeV} / c \]

Assume Acceptance (Region I+II) \( \sim 10\% \)

\[ 0.026 < m^2_{\text{miss}} < 0.068 \ (GeV / c^2)^2 \]
NA48/3 simulation

Gaussian MSC (old)

Non-Gaussian MSC

New MSC

Uncorrelated non gaussian tails

REGION I

REGION II

M(\text{miss})^2 \ (\text{GeV/c}^2)^2
New high-intensity $K^+$ beam for NA48/3

<table>
<thead>
<tr>
<th>Present K12 (NA48/2)</th>
<th>New HI $K^+$</th>
<th>Factor wrt 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS protons per pulse on T10</td>
<td>$1 \times 10^{12}$</td>
<td>$3 \times 10^{12}$</td>
</tr>
<tr>
<td>Duty cycle (s./s.)</td>
<td>4.8 / 16.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Solid angle ($\mu$sterad)</td>
<td>$\approx 0.40$</td>
<td>$\approx 16$</td>
</tr>
<tr>
<td>Av. $K^+$momentum $&lt;p_K&gt;$ (GeV/c)</td>
<td>60</td>
<td>75</td>
</tr>
<tr>
<td>Mom. band RMS: ($\Delta p/p$ in %)</td>
<td>$\approx 4$</td>
<td>$\approx 1$</td>
</tr>
<tr>
<td>Area at Gigatracker (cm$^2$)</td>
<td>$\approx 7.0$</td>
<td>$\approx 20$</td>
</tr>
<tr>
<td>Total beam per pulse (x 10$^7$)</td>
<td>5.5</td>
<td>250</td>
</tr>
<tr>
<td>per Effective spill length MHz</td>
<td>18</td>
<td>800</td>
</tr>
<tr>
<td>MHz/cm$^2$ (gigatracker)</td>
<td>2.5</td>
<td>40</td>
</tr>
<tr>
<td>Eff. running time / yr (pulses)</td>
<td>$3 \times 10^5$</td>
<td>$3.1 \times 10^5$</td>
</tr>
<tr>
<td>$K^+$ decays per year</td>
<td>$1.0 \times 10^{11}$</td>
<td>$4.0 \times 10^{12}$</td>
</tr>
</tbody>
</table>

Already Available
• new rare decay frontier in $K$ physics at CERN
• new experiments planned for $K \rightarrow \pi \nu \nu$ important
• support R&D now for $K^+ \rightarrow \pi^+ \nu \nu$ results $\leq 2010$
P940: Redesign of FNAL-CKM to use Unseparated beam
Conclusions

– Rare kaon decays studies are complementary to those performed at the energy frontier
– There are compelling physics cases that can be addressed with existing proton machines (SPS/MI/AGS)
– Technically challenging experiments but feasible
– Unique opportunity for you to join these efforts!
Back-up Slides
Track Momentum: 15 – 35 GeV/c (RICH limited ?)

Signal Acceptance (Flyo estimation): 3.6% (Region I)

16% (Region II)

Preliminary, G. Ruggiero

Legenda:  
\( \eta_V = \) Veto inefficiency (\( \pi^0 \) or \( \mu \))

Acceptance = Background acceptance (Regions I or II)

\( \eta_{ID} = \) Particle (electron-pion) separation inefficiency

\( \eta_{V\gamma} = \) Veto inefficiency of radiative photon

Formula:

\[
\frac{S}{B} \leq \frac{A_{signal} \times BR_{signal}}{A_{background} \times \eta_V \times BR_{background} \times (\eta_{ID} \text{ or } \eta_{V\gamma})}
\]

<table>
<thead>
<tr>
<th></th>
<th>( K_{e3} )</th>
<th>( K_{\mu2\gamma} )</th>
<th>( \pi^+\pi^0\gamma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>S/B (hyp.)</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>( \eta_V ) (hyp.)</td>
<td>5x10^{-8} (( \pi^0 ))</td>
<td>5x10^{-6} (( \mu ))</td>
<td>5x10^{-8} (( \pi^0 ))</td>
</tr>
<tr>
<td>Acceptance (Flyo)</td>
<td>2% (I)</td>
<td>2.7% (I)</td>
<td>0 (I)</td>
</tr>
<tr>
<td></td>
<td>12% (II)</td>
<td>13% (II)</td>
<td>19% (II)</td>
</tr>
<tr>
<td>Result</td>
<td>( \eta_{ID} &lt; 1.5x10^{-3} ) (I)</td>
<td>( \eta_{V\gamma} &lt; 9x10^{-5} ) (I and II)</td>
<td>( \eta_{V\gamma} &lt; 0.2 ) (II)</td>
</tr>
</tbody>
</table>
GIGATRACKER

• **Specifications:**
  – Momentum resolution to \(\sim 0.5\%\)
  – Angular resolution \(\sim 10\,\mu\text{rad}\)
  – Time resolution \(\sim 100\,\text{ps}\)
  – Minimal material budget
  – Perform all of the above in
    • 800 MHz hadron beam, 40 MHz / cm\(^2\)

• **Hybrid Detector:**
  – SPIBES (Fast Si micro-pixels)
    • Momentum measurement
    • Facilitate pattern recognition in subsequent FTPC
    • Time coincidence with CHOD

FTPc (NA48/2 KABES technology with FADC r/o)
Recent lab test with 25 µm gap

50 µm gap

Width ~30 ns

25 µm gap

Width ~18 ns

Improvement of occupancy observed with 25 µm amplification gap
KABES r/o with 480 MHz FADC

Moriond EW, March 10, 2005

A. Ceccucci, CERN
## Competition

<table>
<thead>
<tr>
<th></th>
<th>NA48/3</th>
<th>P940</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accelerator</strong></td>
<td>CERN-SPS</td>
<td>FNAL-MI</td>
</tr>
<tr>
<td><strong>Energy (GeV)</strong></td>
<td>400</td>
<td>120</td>
</tr>
<tr>
<td><strong>Duty cycle (s /s )</strong></td>
<td>$4.8 / 16.8 = 0.29$</td>
<td>$1.0 / 3.0 = 0.33$</td>
</tr>
<tr>
<td><strong>1 HEP year (s)</strong></td>
<td>$10^7$</td>
<td>$10^7$</td>
</tr>
<tr>
<td><strong>Eff. Spill. Length (s / s)</strong></td>
<td>$3.0 / 4.8 = 0.63$</td>
<td>$1.0 / 1.0$ (?)</td>
</tr>
<tr>
<td><strong>Total Rate (GHz)</strong></td>
<td>0.8</td>
<td>0.23</td>
</tr>
<tr>
<td><strong>Fraction of Kaons (%)</strong></td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td><strong>Flux of Kaons (MHz)</strong></td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td><strong>Decay fraction (%)</strong></td>
<td>9 ($50 \text{ m} / 100 \text{ m}$)</td>
<td>17 ($60 \text{ m} / 67 \text{ m}$)</td>
</tr>
<tr>
<td><strong>Acceptance (%)</strong></td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td><strong>Events/y (BR~10^{-10})</strong></td>
<td>82</td>
<td>31</td>
</tr>
</tbody>
</table>